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Benwadih

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(54) **ORGANIC PHOTODIODE PROVIDED WITH AN ACTIVE ZONE COMPRISING MEANS FOR PROMOTING CHARGE CARRIER COLLECTION AND CONDUCTION**

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USPC 257/40, E21.09, E25.032, 186, 461, 98; 438/94, 82, 69, 99
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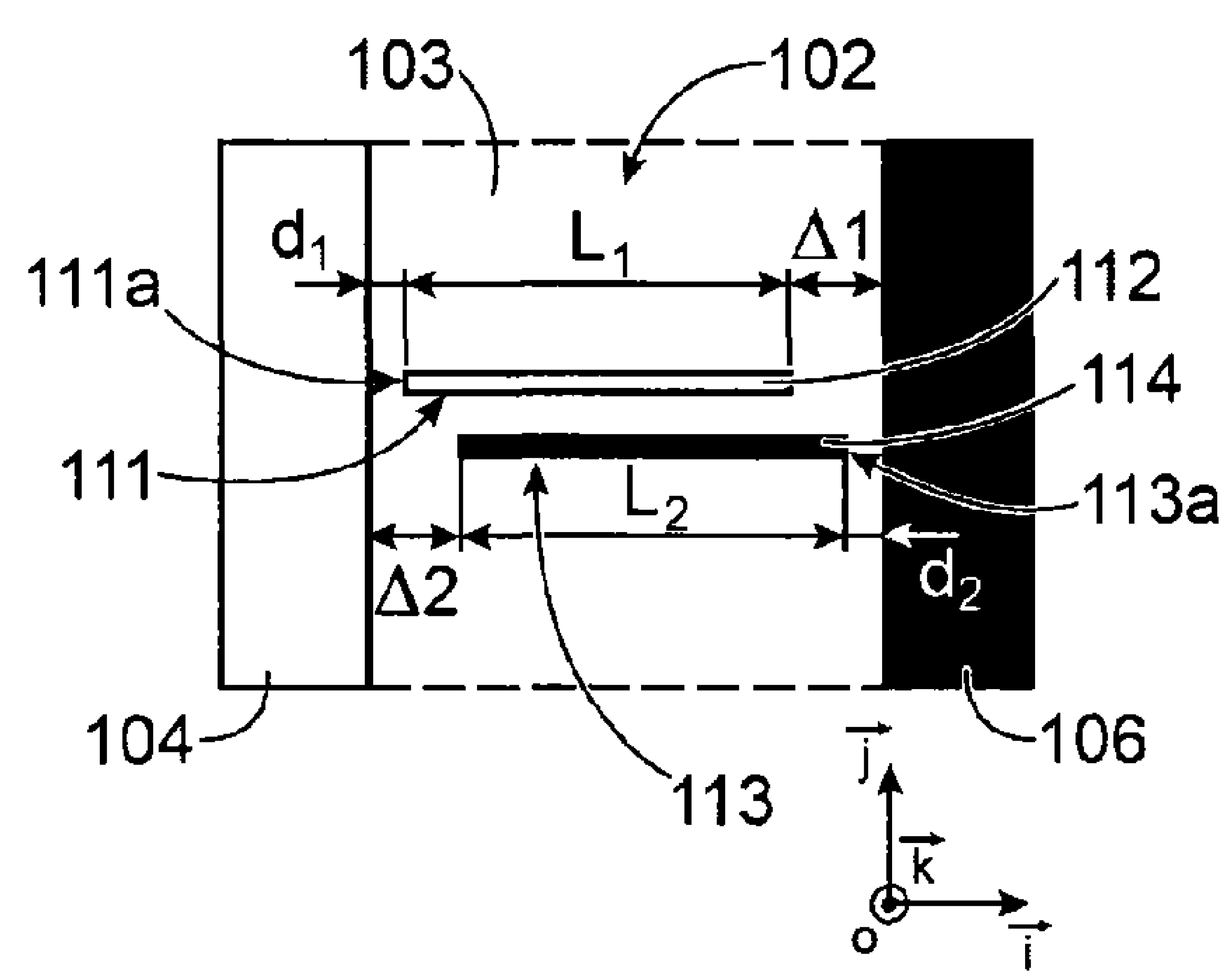
(57) **ABSTRACT**

A photodiode including at least one active zone located between a first electrode and a second electrode, the active zone including elongated conducting or semiconducting elements extending between the electrodes and configured to promote collection and transport of charge carriers in the active zone.

19 Claims, 3 Drawing Sheets



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H01L 51/42	(2006.01)
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H01L 51/00	(2006.01)

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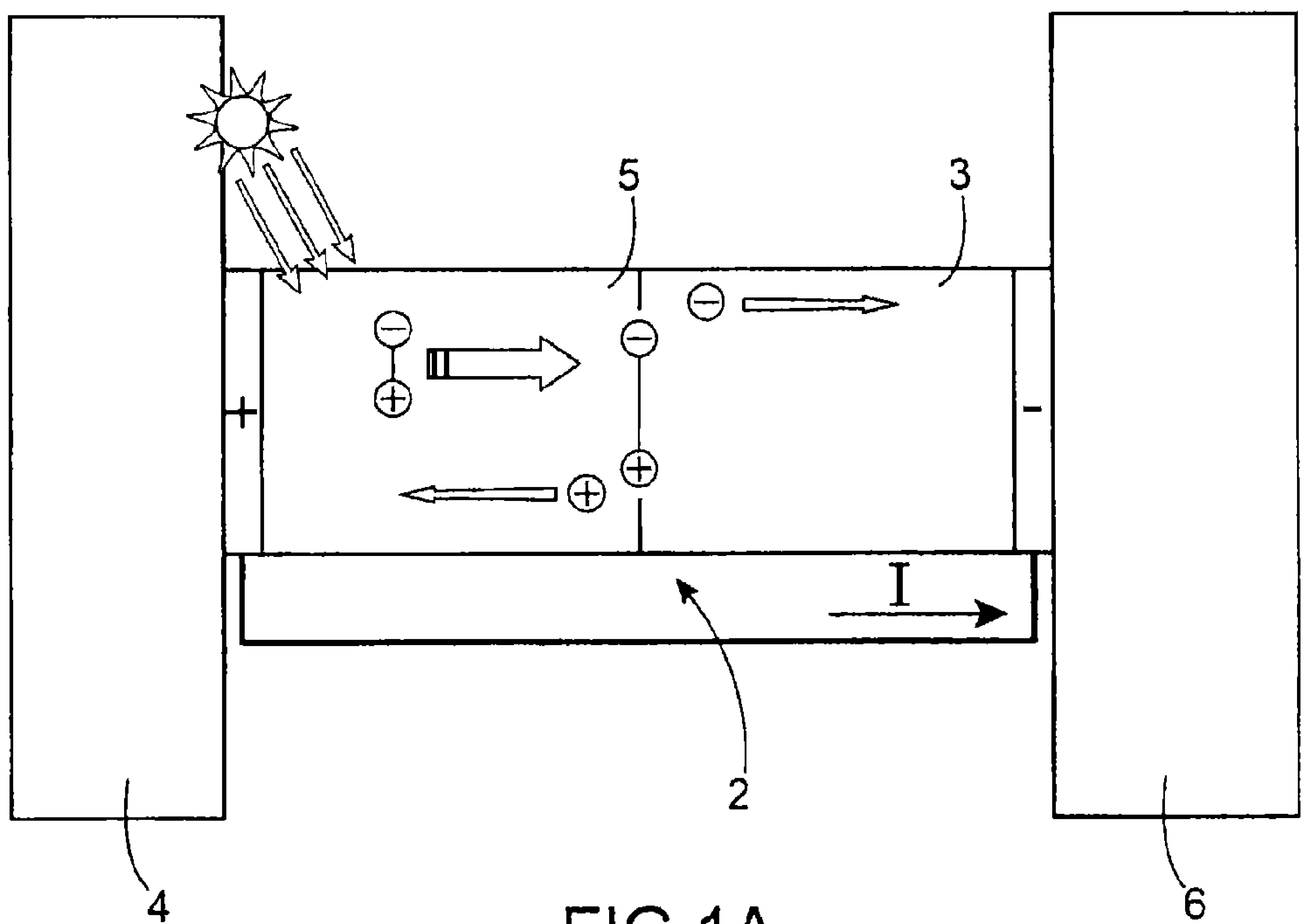

FIG.1A
Prior Art

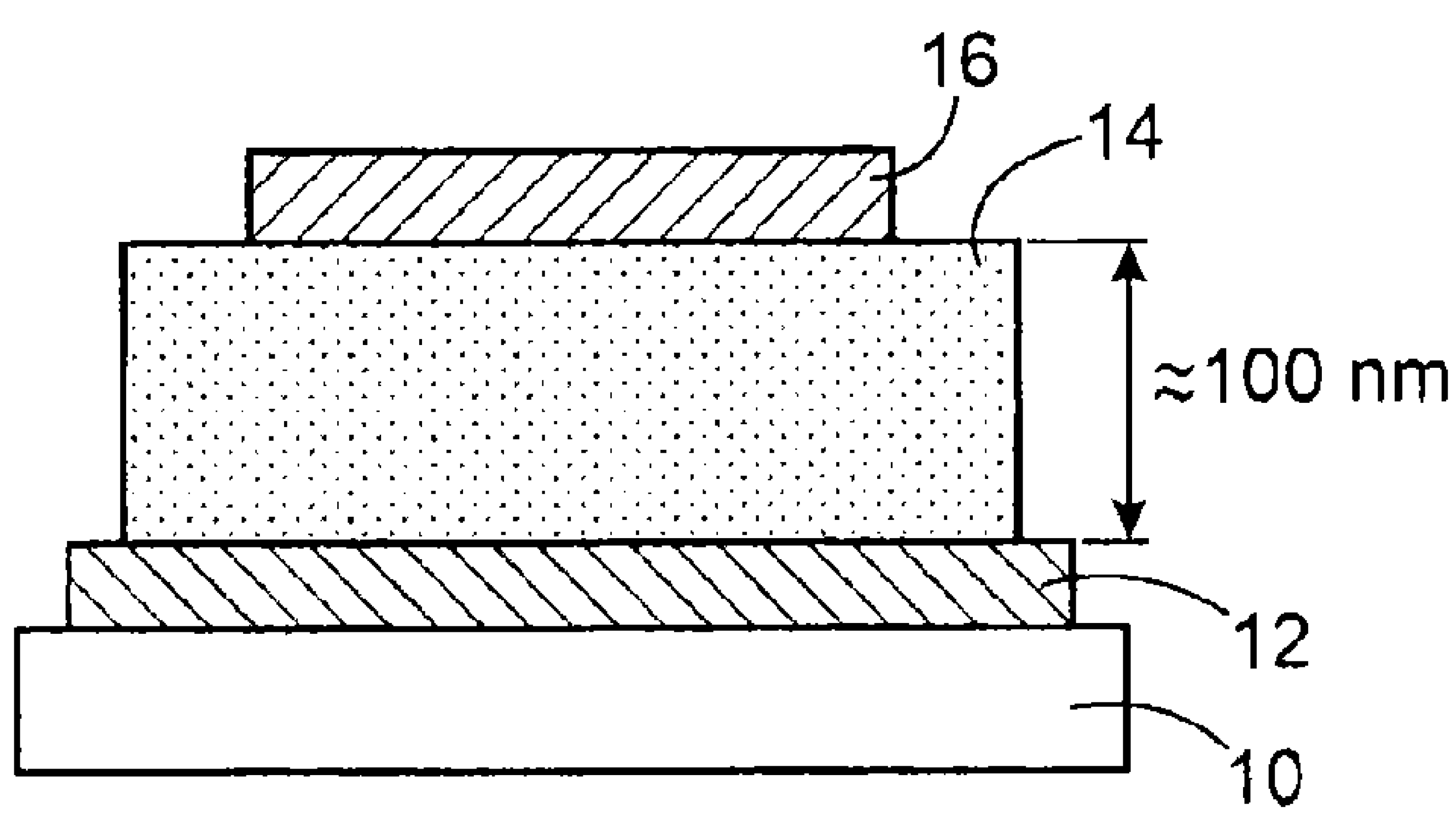

FIG.1B
Prior Art

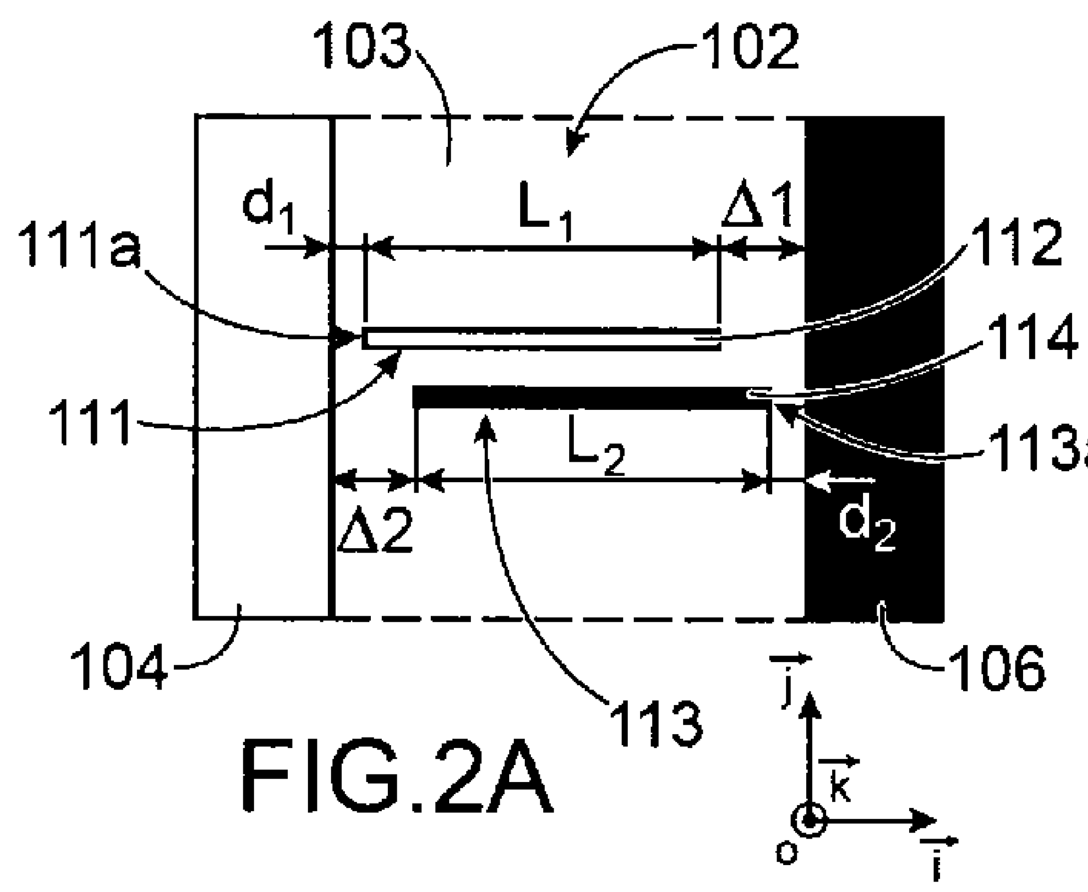

FIG.2A

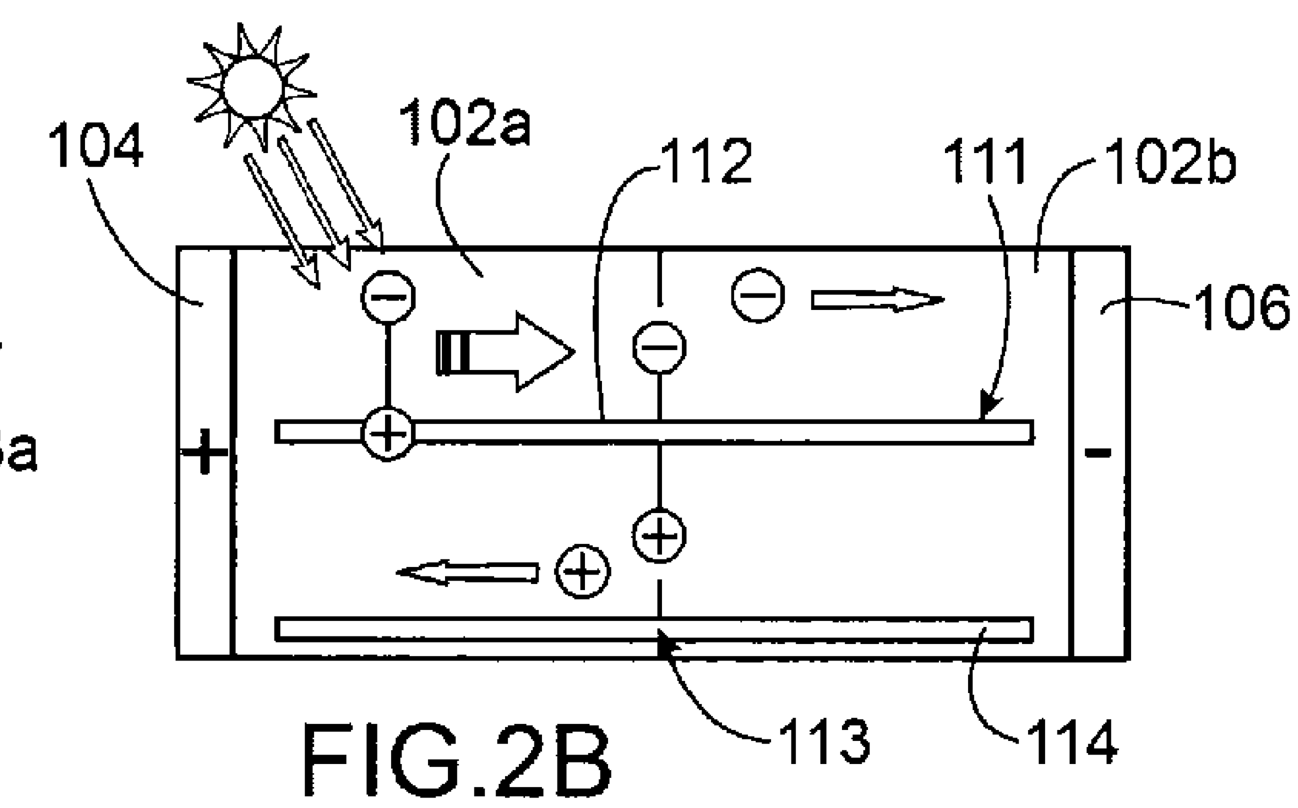

FIG.2B

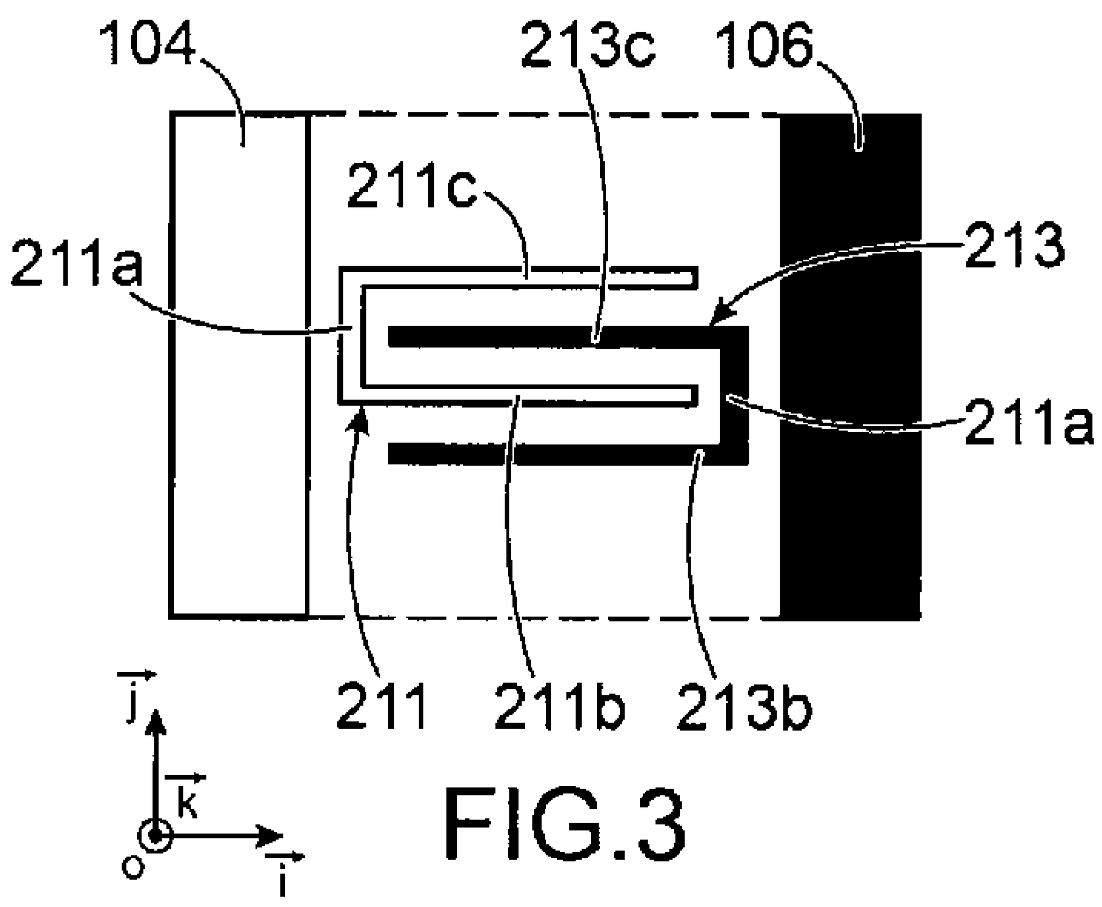

FIG.3

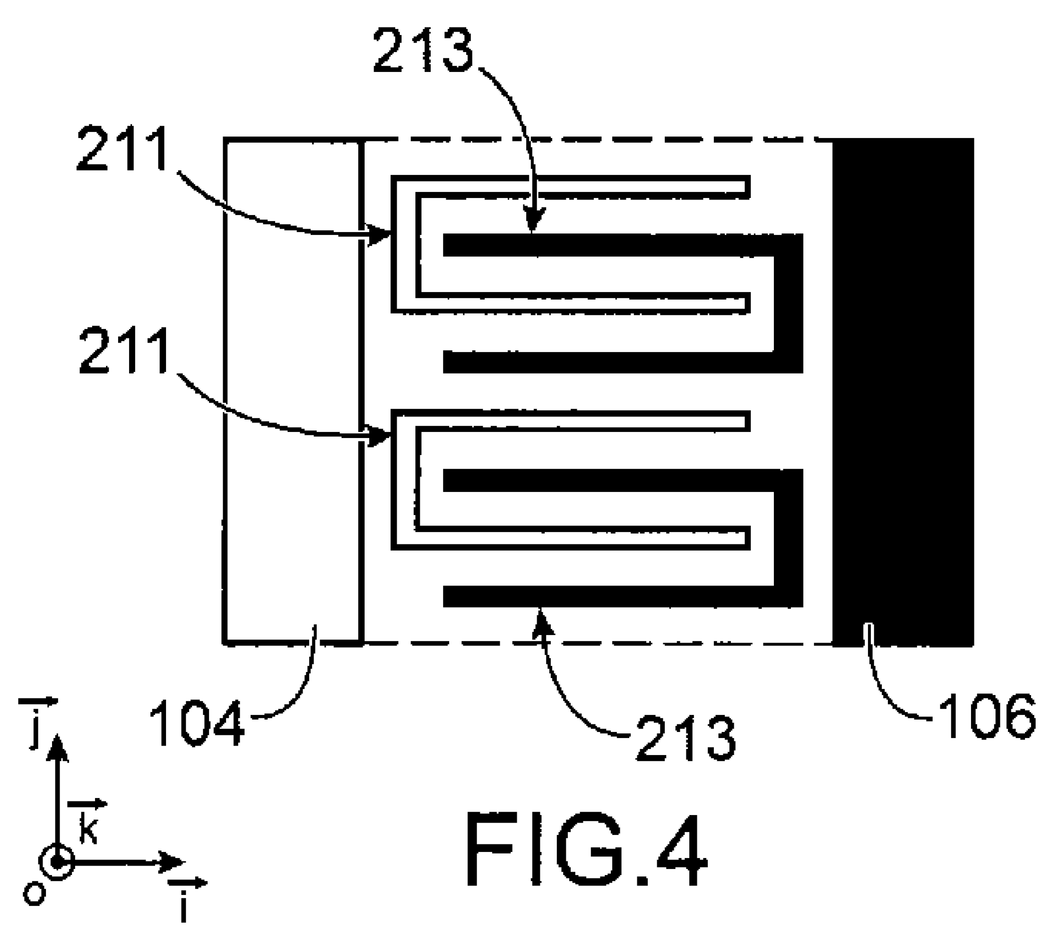

FIG.4

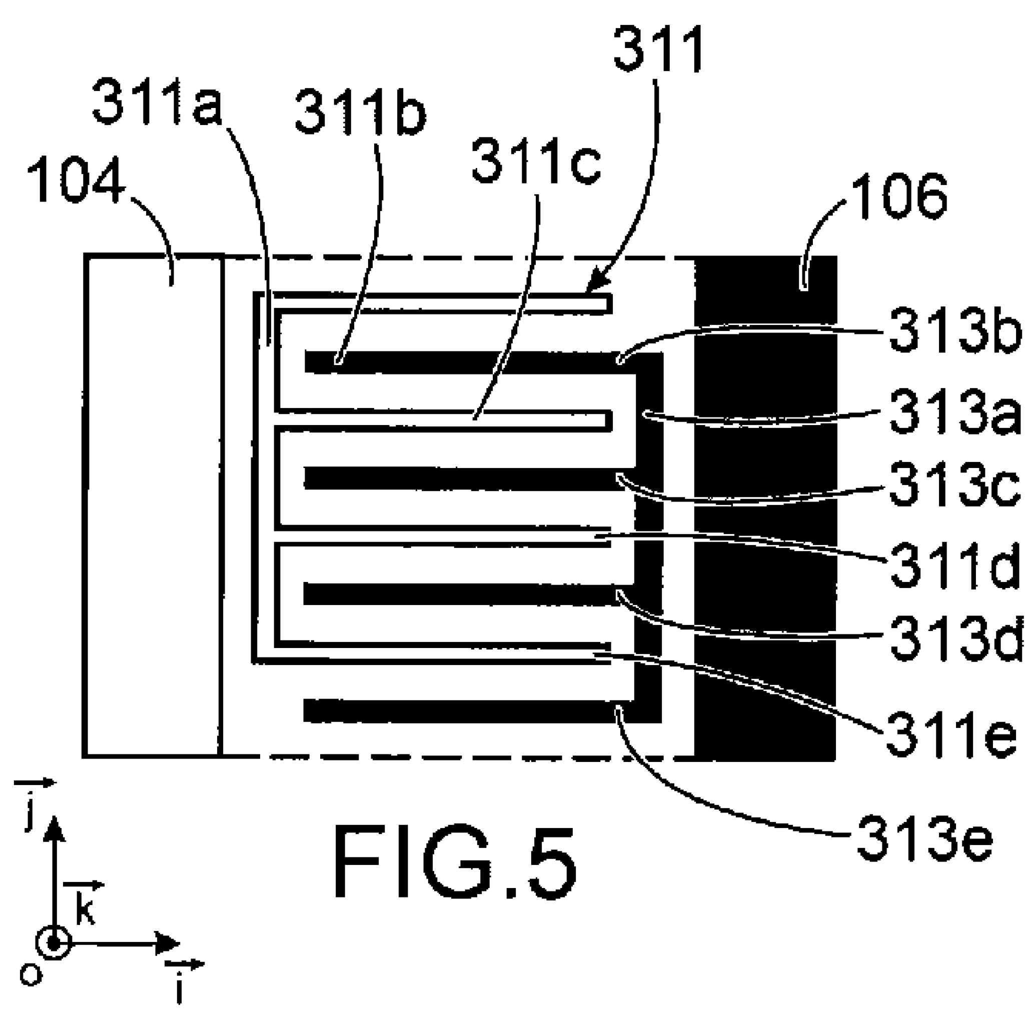

FIG.5

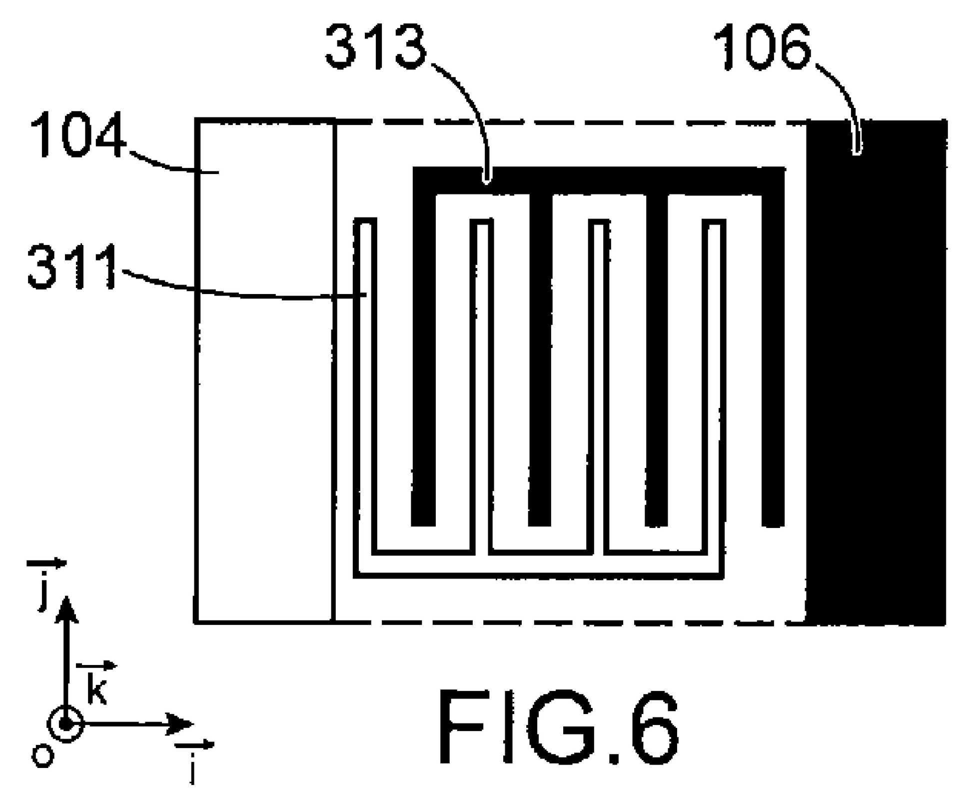

FIG.6

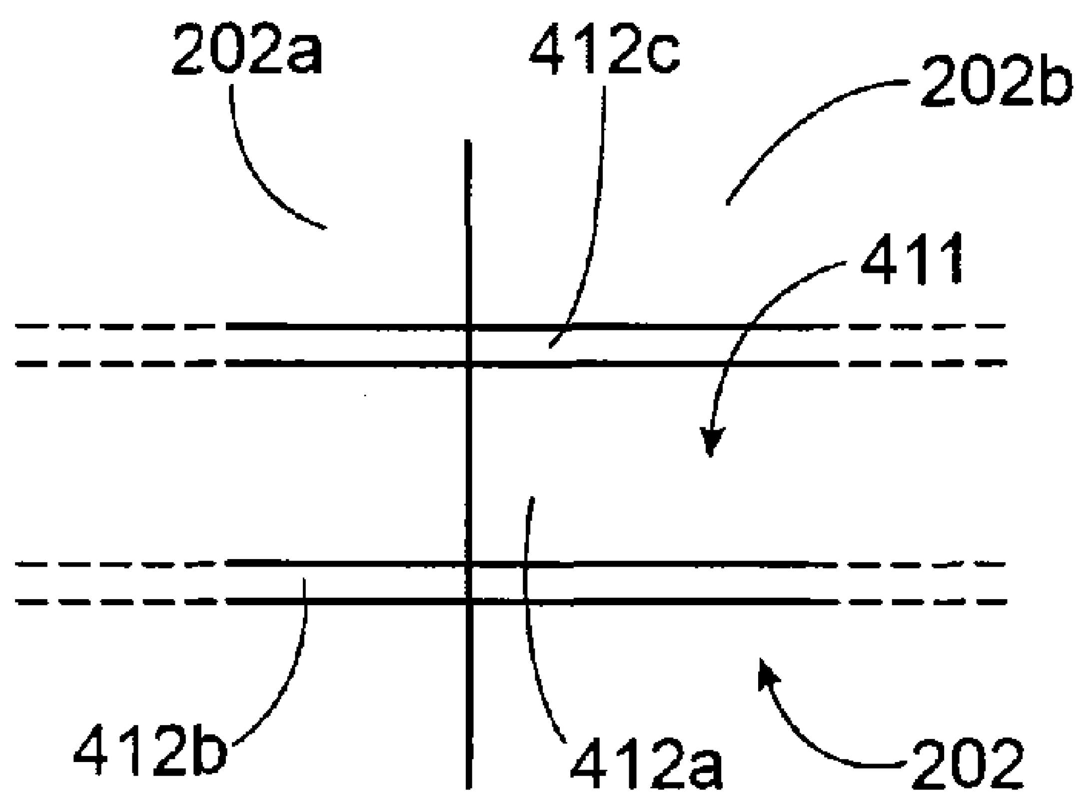

FIG.7

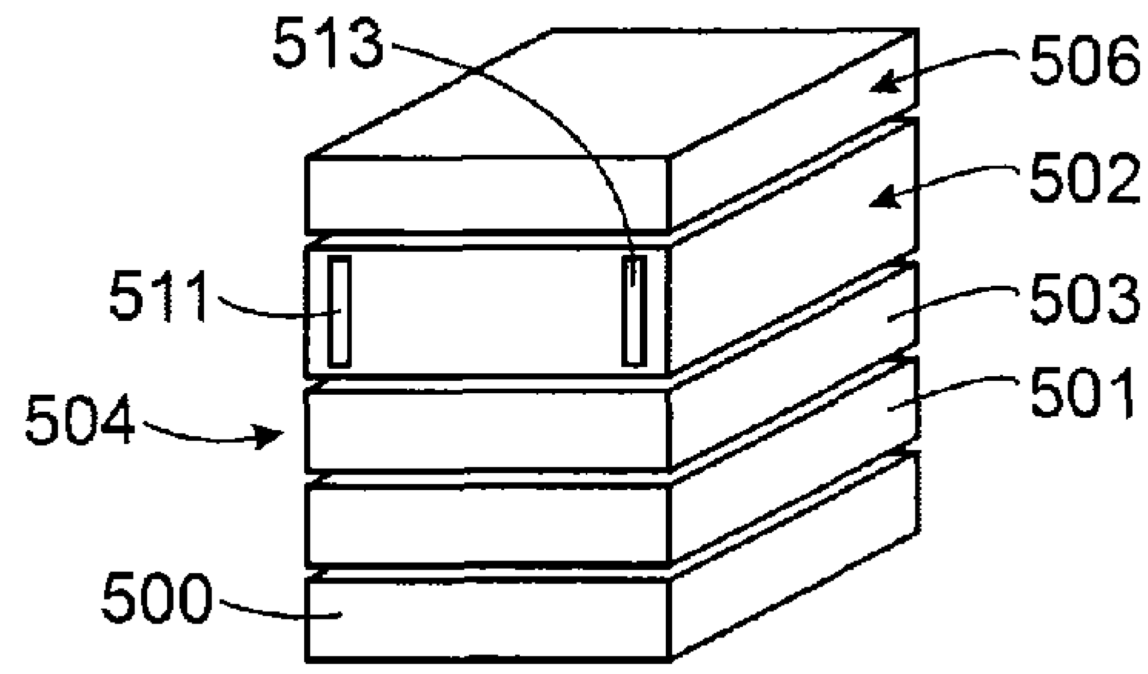

FIG.8

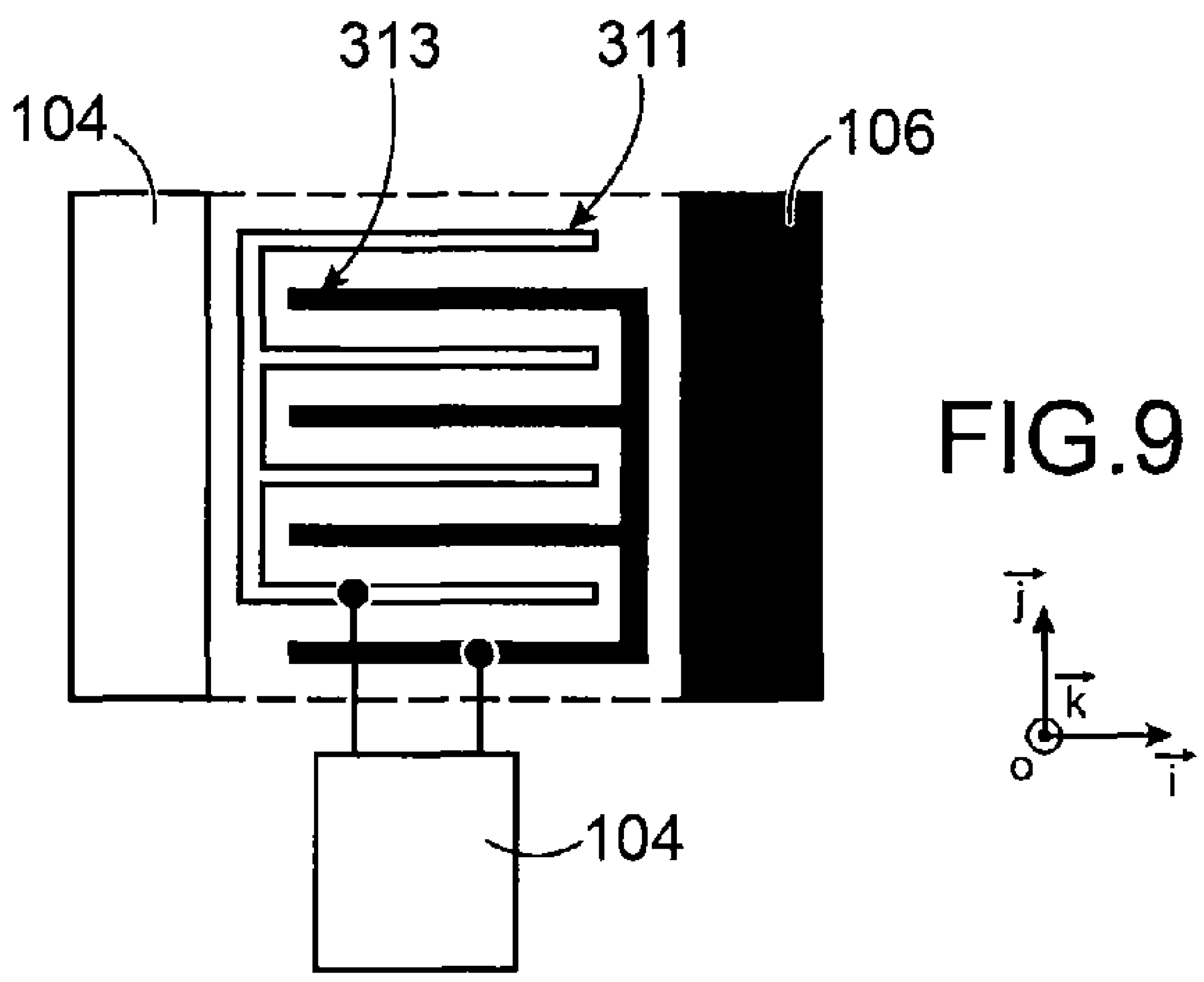

FIG.9

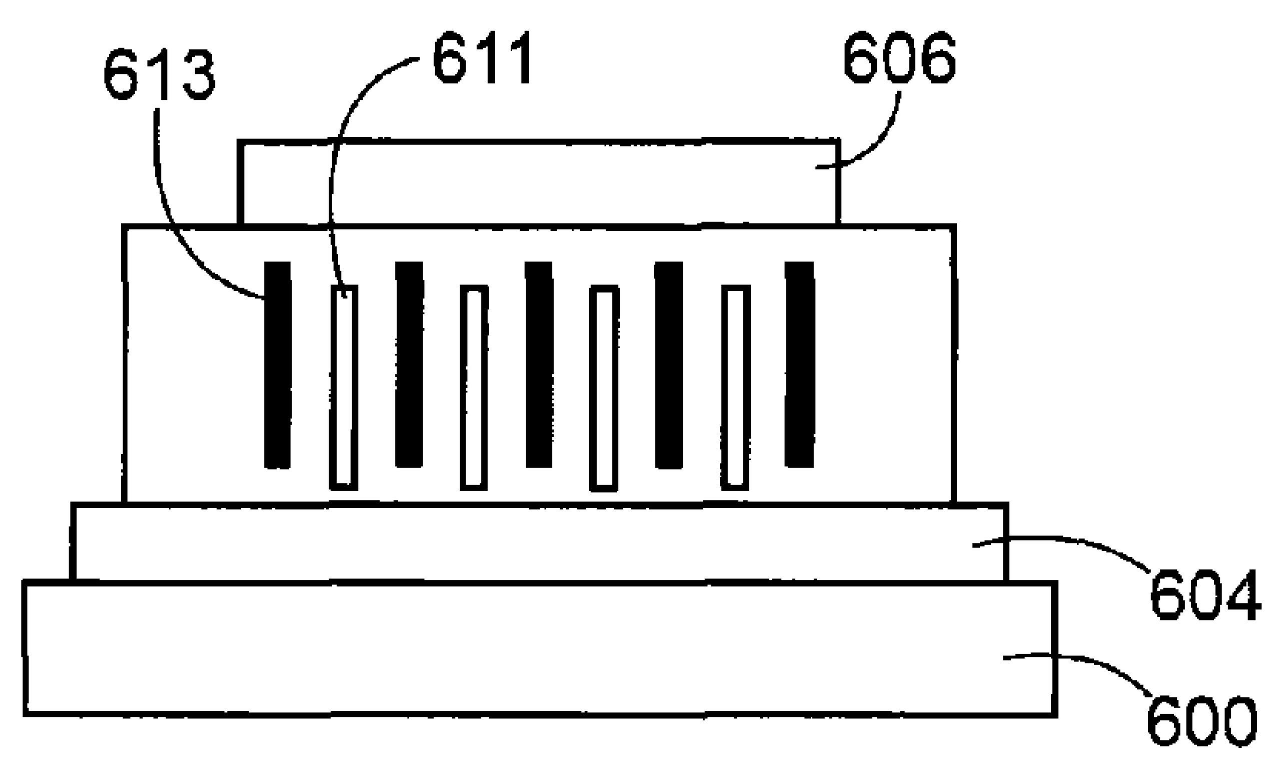

FIG.10

ORGANIC PHOTODIODE PROVIDED WITH AN ACTIVE ZONE COMPRISING MEANS FOR PROMOTING CHARGE CARRIER COLLECTION AND CONDUCTION

TECHNICAL FIELD

This application relates to the field of photodiodes provided with an active zone for conversion of photons into excitons, particularly based on one or more semiconducting polymer materials, and includes a new photodiode structure with an active zone in which collection and transport of charge carriers are improved, and a method for making such a structure.

STATE OF PRIOR ART

In image sensors, photodiodes are components designed to convert quantities of photons representative of brightness levels into proportional electrical magnitudes.

This conversion is made in a zone **2** of the photodiode, usually called the "active" zone and that is located between two electrodes **4** and **6**.

The active zone **2** may be a junction between two regions, a first region **3** based on a first N type semiconducting material that is an electron donor and a second region **5** based on a second P type material that is an electron acceptor (FIG. **1**A).

There are photodiodes for which the active zone is formed from one or more semiconducting materials, the active zone of which is formed from one or more polymer semiconducting materials.

In particular, it is known that these photodiodes can be made by forming active zones 2 based on a mix of polymers comprising at least one electron acceptor polymer and at least one electron donor polymer.

An interaction of photons with such a material can form excitons, in other words pairs of electron holes, which separate to form an electric current.

An example of an organic photodiode according to prior art is given in FIG. **1**B. The photodiode is formed on a substrate **10** covered with an anode **12**, for example based on ITO (Indium Tin Oxide) and PEDOT:PSS, the anode being covered by an active layer **12** formed from a mix of polymer materials comprising a donor polymer and an acceptor polymer material, the active layer **12** itself being covered by a cathode **16**.

With such an active layer material, the life of excitons and the mobility of charge carriers are low. Thus, only a small proportion of electron-hole pairs generated by photons effectively contribute to creating a photo-current.

The efficiency EQE (External Quantum Efficiency) at which photon electrons are converted is a means of quantifying performances of the material in the active layer **12**.

The problem arises of implementing a photodiode with an active zone based on polymer material with an improved EQE efficiency.

PRESENTATION OF THE INVENTION

The invention relates firstly to a component and particularly a diode provided with electrodes, and at least one active zone between these electrodes formed from at least one given semiconducting material, the active zone also comprising one or several elements in the given semiconducting material between the electrodes and based on a conducting or semiconducting material different from said given material.

The conducting or semiconducting elements are formed from elongated zones that extend between electrodes in the given material of the active zone along a direction at a non-zero angle from the electrodes.

The diode may be a photodiode, particularly organic, the active zone of which will generate excitons after absorption of photons.

Among said elements, there may be one or several first elements based on a material promoting conduction of holes.

Said elements may also include one or several second elements based on a material promoting conduction of electrons.

The conducting or semiconducting elements located in the material of the active zone of the diode can improve the efficiency of photon-electron conversion and the collection of charges by electrodes.

With such elements, the collection of charges in the active zone can thus be improved.

In particular, these elements may extend along a direction orthogonal to the electrodes.

Preferably the conducting or semiconducting elements are arranged to not be in contact with the electrodes.

The conducting or semiconducting elements may be in the form of bars or elongated or oblong tracks.

With such elements, drainage of charges may be improved, particularly for devices with a large distance between electrodes, for example of the order of several millimetres.

With such elements, drainage of charges is improved particularly in active zones based on an organic or polymer semiconducting material.

The conducting or semiconducting elements are thus based on a material different from the material used in the regions of the active zone with which these elements are in contact, the material of the conducting elements promoting transport of charges in the active zone.

The conducting or semiconducting elements may thus be designed so as to have better conductivity than the conductivity of the material in the active zone, particularly with a conductivity at least twice as high as the conductivity of the material in the active zone.

According to one particular arrangement, the conducting or semiconducting elements may be formed from a set of tracks arranged in an alternating pattern of tracks promoting conduction of holes and of tracks promoting conduction of electrons.

The area of the junction is thus increased using a donor/acceptor network for the transport of holes to the anode and electrons to the cathode.

According to one possible embodiment, the tracks promoting conduction of holes and the tracks promoting conduction of electrons are arranged in the form of interdigitated combs.

With such an arrangement, the collection and conduction of carriers to electrodes is further improved, while limiting the dimensions.

The first electrode may act as an anode while the second electrode will act as a cathode. In this case, the first element(s) promoting conduction of holes may be located closer to the anode than to the cathode, to improve collection of holes.

According to one possible embodiment, the element(s) promoting conduction of holes may be at a distance d_1 from the anode and at a distance Δ_1 from the cathode, in which $d_1/\Delta_1 \leq 10$.

Elements promoting conduction of electrons may be placed closer to the cathode than to the anode, to be promoting collection of electrons.

According to one possible embodiment, the second element(s) promoting conduction of electrons may be located at a distance d_2 from the cathode and a distance Δ_2 from the anode, such that $d_2/\Delta_2 \leq 10$.

According to one possible embodiment, the total external area of said conducting or semiconducting elements that can be exposed to light radiation, may be designed to be 10 times smaller than the external area of the active zone exposed to this radiation.

This thus limits parasite reflection phenomena.

The thickness of the elements exposed to light radiation may be selected to be less than or equal to 100 nanometres and advantageously less than or equal to 20 nanometres.

This also limits parasite reflection phenomena.

According to one possible embodiment, said elements may be based on an ambipolar material.

According to one possible embodiment, said elements may be based on an ambipolar or semiconducting material selected so that the mobility of charge carriers in this material is higher than, particularly twice as high as, the mobility of charge carriers in the material in the active zone in which said elements are located.

The given material may be a semiconducting polymer material.

According to another possible embodiment, said elements may be based on a polymer conducting material.

According to another possible embodiment, said elements may be based on a metal covered with a layer capable of modifying the work function of said metal, such as a SAM (self assembled monolayer) layer.

According to one possible embodiment of the diode, said elements may include one or several first element(s) based on a P type conducting material chosen from among Au, ITO, Cu, Ni, Ag, Pd, PEDOT:PSS.

According to one possible embodiment of the diode, said element(s) may include one or several second elements based on an N type conducting material chosen from among the following materials Ca, Al.

According to one possible embodiment of the diode, said elements may also include:

one or several element(s) based on a metal covered by a P type SAM layer such as a PFBT or pentafluorobenzenethiol layer,

and/or,

one or several first element(s) based on a metal covered with an N type SAM layer such as a 4MTP or methoxythiolphenol layer.

According to one possible embodiment of the active zone, this zone may be formed from a first region based on said first polymer material and a second region adjacent to the first region and based on said second polymer material, at least one of said elements being based on a metal zone passing through the first region and the second region, the metal zone being covered in said first region by a layer capable of increasing the work function of said metal, the metal zone being also covered in said second region with a layer capable of reducing the work function of said metal.

According to one possible embodiment, the active zone of the component is formed from a mix of a first polymer semiconducting material donor of electrons and a second polymer semiconductor material acceptor of electrons.

The active zone of the component may possibly be formed from a mix of a polymer semiconductor material and an organic semiconductor material.

According to one particular embodiment of the diode, the active zone may advantageously be formed from a mix of PCBM and P3HT, while said elements include first elements based on Au covered with a P3HT-based SAM layer, and second Au-based elements covered with a layer of 4 MTP.

According to one aspect of this particular embodiment, the total external area of the elements that may be exposed to light radiation may be of the order of 20% of the external area of the active zone exposed to this radiation.

This invention also includes a microelectronic device comprising at least one diode like that defined above in which said conducting elements are connected to an external load. This external load may be in the form of at least one capacitor or means forming an accumulator, that is recharged through a current generated by the diode and circulating in said conducting or semiconducting elements.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention will be better understood after reading the description of example embodiments given purely for guidance and in no way limitative, with reference to appended drawings in which:

FIGS. **1**A, **1**B show a photodiode device according to prior art,

FIGS. **2**A-**2**B show an example photodiode according to the invention, with an active zone based on polymers and in which elements are promoting collection and transport of charge carriers in this active zone,

FIG. **3** shows a variant embodiment of a photodiode according to the invention, in which the elements promoting mobility of charge carriers are arranged in the active zone and are in the form of a 'U',

FIG. **4** shows another variant embodiment of the photodiode according to the invention, comprising an active zone with alternating elements promoting mobility of electrons and elements promoting mobility of holes,

FIG. **5** shows another variant embodiment of the photodiode according to the invention, in which the active zone comprises elements promoting collection and transport of holes, and elements promoting collection and transport of electrons, in the form of interdigitated combs,

FIG. **6** shows a variant arrangement of the comb-shaped elements in FIG. **5**,

FIG. **7** shows a particular embodiment of elements passing through the active zone of a photodiode according to the invention designed to improve mobility of charge carriers in this photodiode,

FIG. **8** shows an embodiment of an organic photodiode in the form of a stack of layers according to the invention,

FIG. **9** shows a device in which a photodiode used according to the invention provided with conducting tracks arranged in the active zone and promoting transport of charges in this active zone, can inject a charge current into an external device connected to said conducting or semiconducting tracks,

FIG. **10** shows another example photodiode according to the invention, with an active zone in which vertical elements are promoting collection and transport of holes and in which vertical elements are promoting collection and transport of electrons.

Identical, similar or equivalent parts of the different figures have the same numeric references to facilitate comparisons between one figure and another.

The different parts shown in the figures are not necessarily all at the same scale, to make the figures more easily legible.

DETAILED PRESENTATION OF PARTICULAR EMBODIMENTS

An example diode according to the invention will now be described with reference to FIGS. **2**A-**2**B and **3**.

This diode may be a photodiode comprising a zone **102** called the "active zone" for conversion of photons into excitons located between electrodes **104** and **106**, a first electrode **104** being designed to act as anode, and the second electrode **106** being designed to act as cathode.

For example, the cathode **106** may be based on Al, or Au, or an alloy of Au and Ti, or Indium, or an alloy based on calcium and silver, or a compound of 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline commonly called BCP and silver.

For example, the anode **104** may be based on Mn, or Cr, or Ar, or Indium, or a calcium silver alloy, or a gold and platinum alloy, or ITO (Indium Tin Oxide).

The active zone **102** is formed from at least one semiconducting material **103** and it may comprise at least one semiconducting polymer.

According to one possible embodiment, the material **103** in the active zone **102** may be formed from a mix of polymers comprising at least one electron acceptor polymer and at least one electron donor polymer (FIG. **2**A).

According to another possible embodiment (FIG. **2**B), the material **103** may be formed from a first region **102***a* formed from at least one electron acceptor polymer, and a second region **102***b* adjacent to the first region **102***a* and that is based on at least one electron donor polymer.

The polymer material **103** may be a mix of a P type polymer for example such as poly(3-hexylthiophene) or poly(3-hexylthiophene-2,5-diyl) and commonly called "P3HT", and an N type polymer. The N type material may for example be methyl[6,6]-phenyl-C_{61}-butanoate commonly called "PCBM" on which a polymer may be grafted.

Conducting or semiconducting elements **111**, **113** are provided in the material **103** of the active zone **102** between the electrodes **104** and **106**, to improve collection and circulation of charge carriers.

The elements **111**, **113** are designed particularly with a material to improve transport of charge carriers in the active zone and to be supplied to their corresponding electrodes **104**, **106**.

These elements **111**, **113** extend in the material **103** of the active zone **102** and may be in the form of elongated or oblong shaped tracks or bars. The collection of charge carriers in the active zone to be supplied to their corresponding electrodes **104**, **106** is thus also improved.

A first element **111** based on a first material **112** promoting conduction of holes passes through part of the active zone **102** and extends along the direction of its length L_1 (defined as the direction parallel to the vector $\vec{i}$ of the orthogonal coordinate system $[O; \vec{i}; \vec{j}; \vec{k}]$ given in FIG. **2**A) between electrodes **104** and **106**. The first element **111** enables faster and more efficient collection of holes than an active zone based on material **103** alone and applied according to prior art.

A second element **113** based on a second material **114** promoting conduction of electrons passes through part of the active zone **102** and extends along the direction of its length L_2 (defined along a direction parallel to the vector $\vec{i}$ of the orthogonal coordinate system $[O; \vec{i}; \vec{j}; \vec{k}]$ given in FIG. **2**A) between electrodes **104** and **106**. The second element **113** enables faster and more efficient collection of electrons than an active zone based on material **103** alone and applied according to prior art.

The first element **111** and the second element **113** may be in the form of elongated zones or tracks or rods, with corresponding lengths L_1 and L_2 equal to between 10 nanometres and 100 micrometers.

In the example in FIG. **2**A, the first element **111** and the second element **113** extend along a direction forming a non-zero angle, particularly 90°, with electrodes **104** and **106**.

The first element **111** comprises an end **111***a* or a zone located close to the anode **104** and for example at a spacing from the anode equal to a distance d_1 (defined along a direction parallel to the vector $\vec{i}$ of the orthogonal coordinate system $[O; \vec{i}; \vec{j}; \vec{k}]$) that may for example be between several nanometres and 10 micrometers.

The first element **111** promoting conduction of holes is arranged so that it is further from the cathode **106** than it is from the anode **104**. The first element **111** may be further from the cathode **104** by a distance Δ_1 for example between 1 micrometer and 100 micrometers.

According to one possible embodiment, the distance of the first element **111** from the cathode **104** may be equal to Δ_1 and at least ten times the distance d_1, for example d_1 being equal to 1 μm and Δ_1 being equal to 10 μm, or d_1 equal to 2 μm and Δ_1 equal to 20 μm.

The second element **113** comprises an end or a zone located close to the cathode **106** and for example at a distance from the cathode **106** equal to d_2 (defined along a direction parallel to the vector $\vec{i}$ of the orthogonal coordinate system $[O; \vec{i}; \vec{j}; \vec{k}]$) that may for example be between several nanometres and 10 micrometers. The second element **113** promoting conduction of electrons is arranged further from the anode **104** than from the cathode **106**. The second element **113** may be located at a distance Δ_2 from the anode **104** for example between 1 micrometer and 100 micrometers.

According to one possible embodiment, the second element **113** may be at a distance Δ_2 from the anode **104** equal to at least 10 times d_2, where d_2 is for example equal to 1 μm and Δ_2 is equal to 10 μm, or d_2 is equal to 2 μm while Δ_2 is equal to 20 μm.

The first element **111** is in contact with neither the electrode **104** nor the electrode **106**. Similarly, the second element **113** is not in contact with any of the electrodes **104**, **106**.

In order to minimise reflection phenomena, the first element **111** and the second element **113** may be chosen to be thin for the passage of light radiation that can penetrate into the active zone, less than or equal to 100 nanometres and advantageously less than or equal to 20 nanometres. In this example, the thickness is not the same dimension as the dimension L_1 and is measured along a direction orthogonal to the vector $\vec{i}$, when radiation is expected to penetrate through a face of the active zone **102** parallel to the plane $[O; \vec{i}; \vec{k}]$, and/or when radiation is expected to penetrate through a face of the active zone **102** parallel to the plane $[O; \vec{j}; \vec{k}]$).

To minimise reflection phenomena, the first element **111** and the second element **113** may also be designed such that the area that can be exposed to light radiation will be at least 10 times less than the area of the active zone that can be exposed to this light radiation.

The material **112** promoting conduction of holes can be chosen so that its conductivity σ_1 is higher than the conductivity σ' of holes of the material(s) 103 in the active zone. The conductivity σ_1 of the material **112** may advantageously be such that $\sigma_1 2*\sigma'$.

According to one possible embodiment, the material **112** promoting conduction of holes may be a P type semiconducting material, for example such as 6,13-bis(triisopropylsilylethynyl) TIPS pentacene, chosen such that the mobility μ_1 of holes in this material **112** is at least twice as high as the mobility of holes in the material **103** in the remainder of the active zone **102**.

The material **112** promoting conduction of holes may for example be based on a metallic material such as Au, Ni, Pt or ITO (Indium Tin Oxide), or indium oxide doped with tin) or a P type semiconductor as for example P doped Si.

The material **112** may also be an ambipolar material such as N and P doped Si.

The material **112** may also be a metal for example such as Au covered with an SAM (self assembled monolayer) layer, designed to increase the work function of said metal for holes, and that may be based on a polymer such as PFBT or pentafluorobenzenethiol.

The material **112** may also be an electron donor polymer such as PEDOT poly(3,4-ethylenedioxythiophene).

The material **114** promoting conduction of electrons may itself be chosen so that its conductivity σ_2 exceeds the electron conductivity σ of material **103** of the active zone **102**. The conductivity σ_2 of the material **114** promoting conduction of electrons may advantageously be such that $\sigma_2 \geq 2*\sigma$.

According to one possible embodiment, the material **114** promoting conduction of electrons may be an N type semiconducting material, for example such as diimide perylidene, or ambipolar such as N and P doped Si chosen such that the mobility μ_2 of electrons in this material **114** is at least twice as high as the mobility of electrons in the material **103** in the remainder of the active zone.

The material **114** promoting conduction of electrons may for example be based on a metallic material such as Al, Cu, ITO (Indium Tin Oxide), or an N type semiconductor for example such as N doped Si.

The material **114** may also be based on a metal for example such as Au, that may be covered with an SAM (self assembled monolayer) layer designed to reduce the work function of the metal, and for example based on 4 MTP or 4-methylthiophenol.

According to another possible embodiment, the material **114** may also be based on an ambipolar material, for example such as N or P doped Si or be based on an electron acceptor polymer such as PSS poly(styrene sulfonate).

According to one variant shown in FIG. 2B, the polymer-based active zone **202** may be formed from a first region **202***a* based on an electron donor polymer, adjacent to a second region **202***b* based on an electron acceptor polymer.

When photons are absorbed by the active layer **202**, excitons or electron-hole pairs are generated and then dissociated. The first element **111** promotes conduction of holes to the anode **104**, while the second element **113** is promoting conduction of electrons to the cathode **106**.

FIG. **3** contains another example of an organic photodiode according to the invention.

In this example, a first element **211** in the form of a comb with two branches or a 'U' and based on a material **112** promoting conduction of holes is located in the active zone **102** between electrodes **104** and **106**, while a U-shaped second element **213** based on a material **114** promoting conduction of electrons also passes through part of the active zone **102** between the electrodes **104** and **106**.

The first element **211** comprises a zone **211***a* in the form of a track located close to the anode **104** and extending along the anode **104**, and other tracks **221***b*, **211***c* extending along the cathode **104**. The second element **213** comprises a zone **213***a* in the form of a track located close to the anode **104** extending along the cathode **106**, and other tracks **213***b*, **213***c* extending towards the anode **106**.

The arrangement of the first element **211** relative to the second element **213** may be such that a track **211***b* of the second element is located between the tracks **213***b*, **213***c* of the second element **213** that extend between the electrodes, a track **213***a* of the second element **213** being arranged between the tracks **211***b*, **211***c* of the first element **211** that extend between electrodes **104** and **106**.

The active zone **102** thus comprises alternating tracks promoting conduction of holes and tracks promoting conduction of electrons.

Such an arrangement promotes transport of charge carriers while remaining small in size.

The number of elements **211** and **213** in the volume of the active layer **102** can be increased in order to improve collection of charges. The active layer **102** of the polymer material on the photodiode shown in FIG. **4** has more elements **211**, **213** than the device in FIG. **3**, and in particular two U-shaped elements **211** promoting conduction of electrons and two other U-shaped elements promoting transport of holes.

On the example in FIG. **5**, the photodiode comprises a first element **311** promoting conduction of holes in the material of its active zone **102**, formed from conducting tracks arranged in a first comb and a second element **313** promoting conduction of electrons and formed from conducting tracks formed in a second comb.

The first element **311** comprises an elongated track **311***a* arranged close to and parallel to the anode **104**, and connected to the other tracks **311***b*, **311***c*, **311***d*, **311***e* extending in the direction of the cathode **106**, orthogonal to the electrodes **104**, **106**.

The second element **313** comprises an elongated track **313***a* arranged close to and parallel to the cathode **106**, and connected to other tracks **313***b*, **313***c*, **313***d*, **313***e* extending towards the anode **106** orthogonal to the electrodes **104**, **106**.

The first and the second combs are interdigitated such that the tracks **313***b*, **313***c*, **313***d* of the second element **313** are inserted as teeth between tracks of the first element **311**.

FIG. **6** shows a variant arrangement that is different from the arrangement in FIG. **5** by the orientation of the elements **311** and **313** in the form of combs.

The first element **311** forming the first comb comprises a track forming a comb tooth extending close to and parallel to the anode **104**, while the second element **313** forming the second comb comprises a track forming a comb tooth extending close to and parallel to the cathode **106**.

FIG. **7** shows an another example of a microelectronic device according to the invention, comprising an active zone **202** of the same type as that in the device in FIG. **3**, located between two electrodes (not shown) formed from a first region **202***a* based on an electron donor polymer adjacent to a second region **202***b* based on an electron acceptor polymer.

Elements **411** are provided in the active zone **202** to promote collection of charge carriers. These elements **411** pass through the first region **202***a* and the second region **202***b* and are formed from a metal area **412***a* covered in said first region **202***a* by a layer **412***b* capable of increasing the work function of said metal for the holes, the metal area **412***a* also being covered in said second region **202***b* by another layer **412***c* capable of reducing the work function of said metal.

The layers **412***b*, **412***c* may be SAM (self assembled monolayer) type layers, the layer **412***b* may for example be based on perfluorobenzenethiol, while the layer **412***c* may for example be based on 4-methylthiophenol formed on Au.

FIG. **8** shows one example embodiment of a stack of layers of a photodiode according to the invention.

A first layer **501** for example based on ITO, is formed on a substrate **500** that may be rigid and may for example be made of glass, or flexible and for example based on polymer, and will form a transparent anode **502**. Another layer **503** designed to improve injection in the anode, for example based on PEDOT-PSS and for example of the order of 50 nm thick is then formed on the first layer **501**.

An active layer **502** is then formed that may for example be based on a mix of PZZ and PCBM in a solvent. The active layer **502** may be formed in several deposits, for example by ink jet or by spin coating, or deposited simply by doctor blading.

A first deposit of active material may be made on the layer **503**. One or several conducting or semiconducting elements **511** promoting conduction of holes in the active material are formed. A second deposit of active material is then made and one or several conducting or semiconducting elements **513** are then made facilitating the conduction of electrons on the previously deposited layers of active material.

Another step is to make another deposit of active material to cover the elements **513**.

A layer **506** is then formed to form a cathode. The layer **506** may for example be based on aluminium and may be of the order of 200 nm thick.

The device according to the invention may be used to recharge an external device, for example a capacitor or an accumulator.

The previously described structure on the example in FIG. **9** with reference to FIG. **5** is then used for example to recharge an accumulator.

A first element **311** promoting conduction of holes and formed from conducting tracks arranged in a first comb, is connected to a first electrode of means **400** forming a load, while a second element **313** promoting conduction of electrons and conducting tracks arranged in a second comb is connected to a second electrode of means **400**. In this configuration, the electrodes **104** and **106** of the photodiode are left floating and are not connected to another device.

The photodiode is placed under an illumination provided so as to create charges that will circulate as far as the means **400**. The means **400** may for example be in the form of at least one capacitor or at least one accumulator that is recharged by a current generated in the active zone and circulating in the elements **311**, **313**.

FIG. **10** shows another example photodiode according to the invention. This photodiode is formed on a substrate **600** covered by a cathode **604** above which there is an active zone **602** based on an inorganic semiconducting material, for example based on Ni oxide and Indium oxide, itself covered by an anode **606**.

Elements **611** promoting conduction of holes and elements **613** promoting conduction of electrons are arranged in the active zone **602** along a vertical direction making a non-zero angle with the electrodes extending along a horizontal direction.

The invention claimed is:

1. A diode comprising:

an active zone located between a first electrode and a second electrode, the active zone being formed from at least one semiconducting material, the active zone further comprising one or more conducting or semiconducting elements formed from elongated conducting zones that extend between the electrodes in the material of the active zone along a direction forming a non-zero angle with the electrodes, the elements not being connected to the electrodes and among the elements, one or more first elements is based on a first material promoting conduction of holes, and one or more second elements is based on a second material promoting conduction of electrons, the first material and the second material being based on a material different from the material in the active zone in which the first elements and the second elements are in contact, the first material having a hole conductivity higher than a hole conductivity of the material in the active zone, and the second material promoting conduction of electrons having a conductivity higher than an electron conductivity of the material in the active zone.

2. The diode according to claim **1**, the active zone being formed from at least one semiconducting polymer material.

3. The diode according to claim **2**, the elements being based on a material with better conductivity than the semiconducting material in the active zone.

4. The diode according to claim **1**, wherein the elements are based on a material in which mobility of charge carriers is at least twice as high as mobility of charge carriers in the at least one semiconducting material in the active zone.

5. The diode according to claim **1**, wherein at least one of the elements is based on a conducting polymer material.

6. The diode according to claim **1**, wherein at least one of the elements is based on an ambipolar material.

7. The diode according to claim **1**, wherein the elements include:

at least one element based on a P type conducting material, chosen from among: Au, ITO, Cu, Ni, Ag, Pd, PDOT:PSS,

at least one second element based on an N type conducting material, chosen from among: Ca, Al.

8. The diode according to claim **1**, wherein at least one of the elements is based on a metal covered with a layer capable of modifying work function of the metal.

9. The diode according to claim **8**, wherein the conducting or semiconducting elements further include:

at least one first element based on a metal covered by a P type SAM layer based on PFBT or pentafluorobenzenethiol,

or

at least one first element based on a metal covered by an N type SAM layer based on 4MTP or methoxythiolphenol,

or

at least one or plural first element based on a metal covered by an N type SAM layer based on 4MTP or methoxythiolphenol and at least one first element based on a metal covered by a P type SAM layer based on PFBT or pentafluorobenzenethiol.

10. The diode according to claim **8**, in which the active zone is formed from a first region based on the first polymer material and a second region adjacent to the first region and based on the second polymer material, at least one of the elements being based on a metal zone passing through the first region and the second region, the metal zone being covered in the first region by a layer capable of increasing output work of the metal, the metal zone being also covered in the second region with a layer capable of reducing the output work of the metal.

11. The diode according to claim **1**, wherein the active zone is formed from a mix of a first polymer material and a second polymer material.

12. The diode according to claim **1**, wherein the active zone is formed from a mix of PCBM and P3HT.

13. The diode according to claim **1**, in which elements are formed from a set of tracks, an arrangement of the elements in the active zone forming an alternation of tracks promoting conduction of holes and of tracks promoting conduction of electrons.

14. The diode according to claim **13**, wherein tracks promoting conduction of electrons and tracks promoting conduction of holes are arranged in a form of interdigitated combs.

15. The diode according to claim **14**, wherein the first electrode acts as an anode and the second electrode acts as a cathode, elements promoting conduction of holes being arranged closer to the cathode than to the anode, elements promoting conduction of electrons being arranged closer to the anode than to the cathode.

16. The diode according to claim **15**, wherein elements promoting conduction of holes are arranged at a distance d1 from the cathode at a distance $\Delta 1$ from the anode, and wherein $d1/\Delta 1 \leq 10$, elements promoting conduction of electrons being arranged at a distance not more than d2 from the anode and at least $\Delta 2$ from the cathode, in which $d2/\Delta 2 \leq 10$.

17. The diode according to claim **1**, wherein the conducting or semiconducting elements have a total surface area that can be exposed to light radiation at least 10 times smaller than a surface area of the active zone exposed to the light radiation.

18. The diode according to claim **1**, wherein the conducting or semiconducting elements have a thickness less than 100 nanometers.

19. A microelectronic device comprising at least one diode according to claim **1**, the conducting elements being connected to a load in a form of an accumulator or a capacitor.

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